THE COSMIC RAY ABUNDANCES OF THE PLATINUM-LEAD ELEMENTS AS MEASURED ON HEAO-3

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ABSTRACT

The relative abundances of elements in the charge ranges of $75 \leq Z \leq 79$ (platinum) and $80 \leq Z \leq 83$ (lead) should be a sensitive indication of the contributions of the r- and s-processes in nucleosynthesis. Data from the HEAO 3 Heavy Nuclei Experiment are used to establish abundances, relative to iron, of these elements in the cosmic radiation, as well as the ratio of "secondary" elements, in the $62 \leq Z \leq 74$ range, to the primary lead-platinum elements. These results appear to suggest that either the source abundances are deficient in s-process elements or that they are not organized solely by first ionization potential. In addition, present propagation models can adequately represent the relative abundances of primary and secondary elements.

1. Introduction

The HEAO 3 heavy nuclei experiment was designed to observe nuclei in the cosmic radiation with atomic numbers, Z, between 16 and 100 (Binns et al., 1981). In this paper we report our observations on those elements with Z appreciably above the abundance peak in the $_{50}$Sn-$_{56}$Ba region, with particular emphasis on the abundances in the platinum-lead region. Our earlier conclusions on these abundances have been reported elsewhere (Binns et al., 1982).

A predominant reason to study the abundances of the UH-nuclei is to compare the abundances present in the source of cosmic rays with those abundances predicted by various scenarios of nucleosynthesis. Most of the nuclides in this charge range are synthesized by either the rapid (r-process) or slow (s-process) addition of neutrons to lighter seed nuclei. Thus abundances, such as that characteristic of solar system (SS) material, can be regarded as a mix of predominantly r- and s-process nuclides. The lead-platinum region provides a sensitive test of the mix of the cosmic ray source abundances, since "platinum" (actually $_{76}$Os-$_{78}$Pt) is almost exclusively produced by the r-process, while "lead" is a product of both the r- and s-process. An observed ratio of Pb to Pt, here defined as $P80 = N(80 \leq Z \leq 83)/N(75 \leq Z \leq 79)$, can be compared with values of P80 calculated assuming a particular source value and a model of propagation.

Alternatively P80 can be propagated back to a source and then compared with various possible source values. The results of typical calculations are given in the table, using the propagation codes of Brewster et al. (1983), with and without allowance for the effects of first ionization potentials (FIP). It can be seen that for an exponential escape length of 5.5 g/cm^2 of interstellar hydrogen, the differences in P80 between r- and SS-like material are significant and generally measurable. In these calculations we have used the solar system abundances of Anders and Ebihara (1982) and two versions of r-process abundances, that calculated by us (Israel et al., 1981) from a s-process deconvolution of the solar system abundances of Cameron (1982a), "r_2", and one deduced by Cameron (1982b), "r_1". These differ principally, and sharply, in the derived abundances of lead.

TABLE

Abundance ratios observed and predicted for various source spectra

Source Type	P80 Source	P80 Near Earth	P80 Detector	S70 Source	S70 Near Earth	S70 Detector	S60 Source	S60 Near Earth	S60 Detector
SS	1.34	1.08	1.05	0.088	0.22	0.24	0.22	0.47	0.51
SS(FIP)	1.93	1.48	1.42	0.13	0.26	0.28	0.31	0.67	0.72
r_1-	0.047	0.044	0.042	0.10	0.27	0.29	0.40	0.74	0.80
r_1(FIP)	0.052	0.049	0.048	0.18	0.36	0.38	0.86	1.35	1.43
r_2	0.47	0.42	0.41	0.11	0.26	0.29	0.31	0.61	0.66
r_2(FIP)	0.72	0.63	0.62	0.16	0.31	0.33	0.57	0.93	1.00
Observed No.		22/46			27/68			70/68	
Ratios*		$0.42^{+0.18}_{-0.18}$			$0.40^{+0.09}_{-0.15}$			$1.03^{+0.18}_{-0.22}$	

*Assumes charge resolution dominated by photo-electron statistics.

During propagation the heavy Pb-Pt nuclei will produce lighter secondary fragments which will significantly contribute to the observed abundances of elements in the range $62 \leq Z \leq 74$. We have examined these changes by considering two abundance ratios of secondary to primary elements, $S70 = N(70 \leq Z \leq 74)/N(75 \leq Z \leq 83)$, and $S60 = N(62 \leq Z \leq 69)/N(75 \leq Z \leq 83)$. Predictions for the values of these ratios are also given in the table and again show differences that should be measurable. The significance of these results is discussed by Klarmann et al. in paper OG5.2-13. Also shown in the table are ratios corrected for the effects of the overlying matter in the detector. This correction is only approximate and has been obtained by assuming that the 1.5 g/cm^2 of Al overlying the detector can be represented by a slab of 0.15 g/cm^2 of Hydrogen for nuclei with $Z \geq 60$.

2. Analysis

From the data collected over a period of 574 days, we selected all events for which any of the ion chamber signals or the sum of the Cherenkov signals was greater than what would be produced by a $Z = 60$ particle, assuming Z^2 scaling from iron. Along with the true $Z > 60$ events this data set included many lower charge and spurious events which were subsequently rejected. Events with high ionization due to their having low energy were rejected by the relative magnitude of Cherenkov and ion chamber signals. Events in which a spurious coincident particle hit a photomultiplier or an ion chamber were rejected by requiring consistency of signals among Cherenkov elements or ion chambers. Events in which the particle trajectory was not well enough defined to give reliable charge estimates were also rejected. Of these criteria only the last may be significantly charge dependent, since higher Z nuclei can be expected to produce more knock-on electrons capable of triggering additional hodoscope wires. However, by keeping these criteria quite relaxed, the influence of any charge dependent effects has been minimized.

The result of our selections is a file of events that was then individually examined, enabling us to identify several further small classes of nonacceptable events. The experience gained from this event by event analysis has allowed us to construct algorithms that can be systematically applied to the data to produce a final "good" data set of 166 events with $Z \geq 62$.

We have then to determine the best available charge estimates for this data set. This problem has been approached by using the abundant iron nuclei, $Z = 26$, to normalize both the abundances and charge scales. Some 12,000 $Z = 26$ events were selected from a representative sample of the original data. As part of the selection process, particles were separated into various groups, depending on whether they had low or high geomagnetic cutoffs, and whether the signals implied the particles had medium or high energies. For each of these groups the iron nuclei provided a well-defined charge peak that has been used to fix the charge scale at $Z = 26$. If the signals are assumed to scale as Z^2 then this also determines the charge scale in the $60 < Z \leq 90$ region. Our calibration with beams of Mn and Au nuclei (Garrard et al., paper T2-10) was only to energies up to 960 MeV/amu for Au and showed distinct non Z^2 effects in ionization response but much smaller non Z^2 effects in Cherenkov response. In the present paper we deal only with high energy (greater than 1.5 GeV/amu) nuclei for which the charge assignment is based on the Cherenkov signal. While we have no direct calibrations at these energies, the lack of strong deviations from Z^2 Cherenkov responses in our calibration leads us to adopt a simple Z^2 response here.

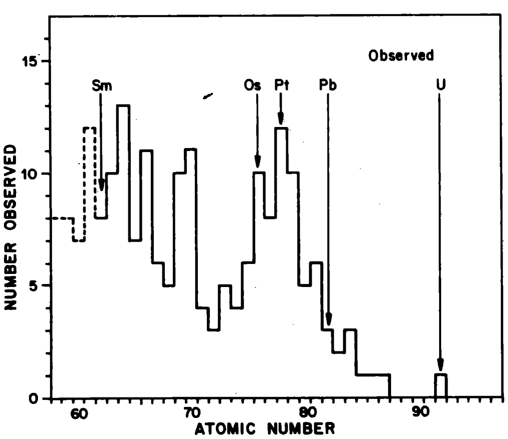

Fig. 1. The observed numbers of nuclei with $Z \gtrsim 58$. All Z assignments are based on Cherenkov signals.

3. Results

Our charge spectrum is given in Fig. 1, which shows the actual numbers of measured particles. These abundances have been normalized to $(17.4 \pm 1.0) \times 10^6$ iron nuclei in the detector, assuming no Z dependent selection effects. They can be approximately corrected to near earth space by an 11% correction for losses due to interactions within the detector and by 9%, 4%, and 0% corrections for the "Pb", "Pt" and secondary elements due to propagation through the front window.

The table shows the observed counts for P80, S70 and S60. By considering the observed resolution of the iron peaks in the data set, we have estimated the possible effects of charge smearing on these ratios and show in the table our deduced values for each ratio together with their estimated uncertainties.

4. Conclusions

The cosmic ray abundances, when compared with the solar system, appear to be depleted in lead by a factor of at least two to three. Similarly, we also find that in the Sn-Ce region the ratio of r-process to s-process contribution to the cosmic ray source abundances (taking account of FIP effects) is $1.5^{+0.8}_{-0.5}$ times the corresponding ratio in the solar system (Stone et al., paper OG1-21).

One interpretation of the Pb depletion would note that Pb is one of the few volatile elements with low FIP (Meyer, 1981). If volatility rather than FIP is the organizing parameter for cosmic ray source depletion, then an underabundance of lead would be expected, while there would be a smaller effect in the Sn-Ce region, since although Sn like Pb is a low FIP volatile s-process element, the s-process in that region is not only determined by Sn. In this interpretation it may not be necessary to require any depletion of the abundances of s-process nuclides.

An alternative interpretation of these two results is that both indicate an s-process depletion which implies that the source composition is measurably different from that of solar system matter.

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